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NATURE OF THE DETERIORATION MECHANISM OF HIGH-ALLOY
STEELS DURING SWAGING

M. V. Rastegayev

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[Figure 4 is appended. Remaining figures are available in original in CIA.]

It is known that a number of high-alloy steels have low indexes of plasticity. Hot working of these alloys has not been properly studied. The purpose of the present investigation is to reveal experimentally a direct cause for failure of these alloys during shaping. The plasticity of several steels of this type was investigated. This paper deals with one of these alloys as most characteristic by its brittleness.

The alloy in the shape of an ingot 35 millimeters in diameter was forged under a flat hammer and in semicircular dies at various temperatures. It showed brittleness in every kind of working. The ingots were deteriorated under the first blows, forming a stone-like fracture (Figure 1). In the case of forging at high temperatures a fracture acquired a needle-like appearance suggesting dendritic structure (Figure 2). These two types of fracture indicate ~~an~~ certain relationship between the disintegration of the metal and the phase condition of the interlayers formed in the zone of failure.

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It was decided to establish experimentally the shape and position of these layers, and the temperature boundaries of their formation. The method of gradient heating was used.

Specimens in the shape of 2x6x130 millimeter strips were cut out of ingots. Each specimen was inserted into a porcelain tube 8 millimeters in diameter and placed together with the tube into a hot furnace in such a way that one end of the specimen protruded out of the furnace, whereas the other end was kept in the high-temperature atmosphere. Constant temperature was maintained in the furnace. Another porcelain tube, housing a platinum thermocouple with a bare hot joint, was placed next to the tube with the specimen. The thermocouple could be moved in the tube for a distance corresponding to the specimen length. Temperature was registered every centimeter of thermocouple travel.

Upon heating the specimen was pushed out of the tube into cold water for fixing all structures obtained by gradient heating along the length of strip. A microspecimen was prepared from the strip in the longitudinal direction and etched.

To study the formation of the network of interlayers, photomicrographs were taken by a continuous method at X33 and X1000 magnifications for the temperature range from 400 to 1270°C.

Separate elements of a continuous micrograph, taken at X1000 magnification, are given in Figure 3. The metal maintains

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dendritic structure (Figure 3, 400°) to 1220°. At this temperature range the light-colored phase is gradually coagulated, the process being completed at 1200° with the formation of light globules (Figure 3, 1221°), the microhardness of which amounts to 260-285 at room temperature. Under further heating light globules begin to dissolve partially, merging simultaneously together and forming strings (Figure 3, 1231°) and films; their microhardness increases to 425. A light phase with microhardness up to 700 is accumulated at junctions of films (indicated by the arrow in Figure 3, 1239°). Still further, separate films come together and form grain boundaries (Figure 3, 1256° and 1267°), i.e., a continuous network of interlayers of microhardness up to 300-400 with microhardness of grains between 160 and 220.

At temperatures above 1270° the network, being fused first of all, causes the formation of a needle-like fraction upon deterioration of the alloy during deformation at high temperatures.

In the 1216-1256°-range, light globules lose their bond with the base mass of alloy in the process of their conglomeration into strings and films. Careless grinding and polishing of a specimen may result in the crumbling-out of globules, creating darkened depressions (Figure 3, 1216°, 1221°, 1231°, 1239° and 1256°). Disrupted bond between globules and base metal is a cause of stone-like fracture of alloy during deformation at lowered temperatures. It appears that globules may form strings,

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films and networks not only in the process of heating the alloy, but also in the process of deformation if this deformation is realized nonuniformly.

Nonuniform deformation may be realized by various methods [1]. The clearest picture of it may be obtained by swaging a cylindrical specimen with a flat hammer, when outer friction exists between the specimen end surface and hammer. With a sufficient degree of friction, the end surface of a specimen (f_0 in Figure 4) may be entirely wedged on the hammer surface; this phenomenon creates the zones I and II of restrained deformation which, like conical wedges, squeeze out metal in the direction of arrows C-C.

The process of squeezing out is accompanied by considerable shear deformation on the surface parting the restrained zone of deformation (conical wedge) and extruded metal. As a result, the metal layer at the separation surface is overheated. The degree of overheating depends on the rate and extent of deformation and on the thermal conductivity of the deformed metal.

The greater the deformation extent and rate of the specimen and the lower the thermal conductivity of the deformed metal, the greater will be the degree of overheating of the metal layer under conditions of nonuniform deformation.

The shape of the separation surface varies in the process of swaging. In Figure 4, the dotted line $a_0b_0a_0$ shows a

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separation surface at the initial stage, and line a b a at the final stage of the swaging process. Depending on the degree of overheating, the metal layer at the separation surface undergoes structural modifications similar to those observed in gradient heating. This assumption was experimentally verified for a number of high-alloy steels.

Experimental data for one of these steels, as the most characteristic alloy, are presented here. Cylindrical specimens 21 millimeters in height and diameter were swaged by a drop hammer with 90 kilograms weight from various levels and at various temperatures. Results are given in the following table.

No of Specimen	Temperature, °C	Swaging Degree, %	Lift of Ram, m	Results
3 - 1	1220	55.0	2	Disintegration
3 - 2	1170	36.4	2	Shear cracks on side surface
3 - 3	1100	27.0	2	Single shear crack on side surface
3 - 4	1000	36.0	3	Through shear cracks on side surface
3 - 5	1170	17.9	1	Single crack just marked
3 - 6	1100	15.0	1	No cracks

Figure 5 demonstrates the appearance of the cracks on the side surface of a specimen. The table and Figure 5 show that cracks do not appear only with small degrees of swaging, not exceeding

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15 o/o. At great degrees of swaging (55 o/o) and at a high temperature (1220°) the specimen disintegrates considerably under action of conical wedges which squeeze out metal in the direction of arrows C - C (Figure 4; Figure 5, specimen 3-1; Figure 6). Crack formation begins from a contact surface at points a (Figure 4). Cracks become deeper along the separation surface aba. Microanalysis near the cracks completely corroborated the assumption on the structural modifications in the overheated metal layer at the separation surface aba.

Figure 7 represents a micrograph of structure in the zone of the crack end marked by the letter d in Figure 6. A crack, terminated at the point marked by l, may be seen in the upper left corner. The dark band of the metal layer is a continuation of this crack.

As result of extensive displacement of the squeezed-out metal A along the surface of the zone of restrained deformation B, the layers adjoining crack and band were overheated above specimen temperature, i.e., above 1220°. Segregations of light globules in the form of bands with separation points 2 and 3 may be observed in the layer adjacent to the crack. The globules formed a kind of film from which they crumbled out during polishing, leaving darkened depressions. The crack itself does not reveal any band of globules since deterioration occurred along

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that band. But near the edges of the crack, formation of globules from the broken network may be noticed on the side of the squeezed-out metal A; and traces of crumbled amalgamated globules may be seen on the side of the restrained zone B.

A second band, 1-2 microns thick, with considerable segregation of light globules is located in the metal parallel to the crack edge and band 1-2-3, at a distance of about 20 microns. This band is indicated by the arrow with the letter a. It is dark in its upper part 4, showing that merging and crumbling-out of globules occurred at this point.

Still lower under the band a, a wider strip or band, b, is located at a distance of about 60 microns from the crack. The thickness of this band is approximately 30 microns. Globules within this band are arranged in strings and form a network, as was observed in the case of gradient heating (Figure 3, 1231° and 1256°). The globules are distributed uniformly in the lower part of the band, but they are crumbled out in some places in the upper part.

Thus, it was demonstrated that, in the process of swaging the specimen, bands of the metal layer at the separation surface undergo structural modifications approximately similar to those observed during ordinary heating of the alloy. These bands may acquire various thicknesses and structures due to the degree of overheating during nonuniform deformation.

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Globules in more overheated bands lose their bond with the basic mass of the alloy during the process of merging. In this case failure of the metal takes place along these bands.

Consequently, a direct cause for the deterioration of brittle high-alloy steels is phase transformation in the metal bands formed near the separating surfaces of the squeezed-out metal and restrained zones of deformation, during the process of nonuniform deformation. One question remains unclarified: how a decrease of omnidirectional compression occurs in the process of deforming the specimen with a flat hammer.

Figure 4 represents schematically, the destruction of the specimen 3-1 (Figure 6), which was heated to 1220° and swaged 55% between flat die members of a drop hammer.

Face surfaces f_0 of the specimen, being covered with scale, were wedged by die members. In the initial stage of swaging, the oxidized (scale-covered) side surface of the specimen was moved on the contact surfaces, encountering in its shifting the resistance of the flat die faces. Thus, the contact surfaces maintained intact in the swaging process up to dimension f , when the following phenomenon took place. Overheating of the metal layer at separation surface aba occurs in the deformation process as previously described. The temperature at these points rises above the original temperature of the specimen and initiates the process of merging the globules into strings,

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films and network; i.e., the process, observed on micrographs for 1230-1270°, begins its development. Due to this factor the original bond is disrupted between restrained deformation zone and metal under the squeezing-out pressure; the extruded metal moves along weakened portions of the metal layer at the separating surface. From this moment transition of the side surface to contact surfaces is interrupted. Instead, metal begins to be squeezed out in the shape of a wedge. Overheated metal without scale moves to the contact surfaces from the region beneath the zones of hampered deformation. Friction between extruded metal and die faces decreases and, as a result, "slippage" of portions k of extruded metal along the die surface takes place. Since the contact surfaces f remain wedged in the die faces, these portions k have inevitably to break away from the contact surfaces f at points a for a value s.

The cracks thus formed continue to develop to the extent permitted by decrease of omnidirectional compression.

In contrast to longitudinal shear cracks, described by S. I. Gubkin [1], the author suggests^{ts} the term "slippage cracks" for the cracks here described. They differ from shear cracks in that their formation begins from the contact surface while shear cracks originate from the side surface. Structural modifications of bands in the metal layer at the separating surface may occur only in the case when these bands, in the

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overheating process, reach the phase transformation temperature of the given alloy, which usually reveals high plasticity in the absence of such a transformation.

An example to this effect may be presented by the deformation of carbon steel in the single-phase gamma-region under the condition that the metal is not preliminarily overheated up to the solidus line. Intensive swaging of carbon steel at room temperature may create a condition where a band of the metal layer will be overheated and will become austenitic.

Cold layers of metal adjoining the austenitic band, draw off heat at an extremely high rate. As a result, hardening of the band takes place producing a martensitic structure. It should be noticed that the thermal conductivity of carbon steels is higher than that of high-alloy steels. For the first time, bands in carbon steels were detected by V. P. Kravtsov-Tarnavskiy [2]. M. M. Davidov [3] and N. Ya. Solov'ov [4] established later that these bands are martensitic.

The author's experiments corroborated the presence of Kravtsov-Tarnavskiy bands in carbon steel not only in specimens swaged at room temperature but at all temperatures up to the point A, (Figure 8, 1000°). At the same time, such bands were not detected in swaged specimens heated gradually in the temperature range of the gamma-region (Figure 9).

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Institute of Metallurgy imeni

A. A. Baykov, Academy of Sciences of the USSR.

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Captions under Illustrations

Figure 1. Deterioration of the Ingot During Working--"stone-like" fracture.

Figure 2. Deterioration of the Ingot During Working--"needle-like" fracture.

Figure 3. Photomicrographs of an ingot of high-alloy steel subjected to gradient heating at 400-1270°C range. Magnification: X1000.

Figure 4. Schematic Drawing Showing Formation of "Slippage Cracks" During the Swaging of a Cylindrical Specimen with Flat Face Dies.

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Figure 5. Crack Formation in Specimens of a Brittle Alloy in Respect to the Extent of Swaging with Flat Face Dies.

Figure 6. Cross-Sectional View of Specimen 3-1 (Figure 5)

Figure 7. Microstructure of the Overheated Metal Layer Obtained in the Process of Nonuniform Deformation of Specimen 3-1 (Figure 6). X500

Figure 8. Two Parallel Bands (Indicated by Arrows), Formed as Result of Swaging a 5x5x60 millimeter Specimen Heated Gradiently in 425-700 Range. Steel U-8

Figure 9. Specimen (5x5x60 millimeter) Heated Gradiently in 750-950° Range and Swaged Under Drop Hammer with Flat Face Die; Bands Did not Appear. Steel U-8

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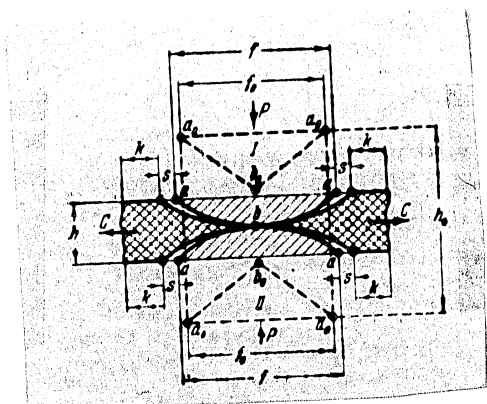


Fig. 4.

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